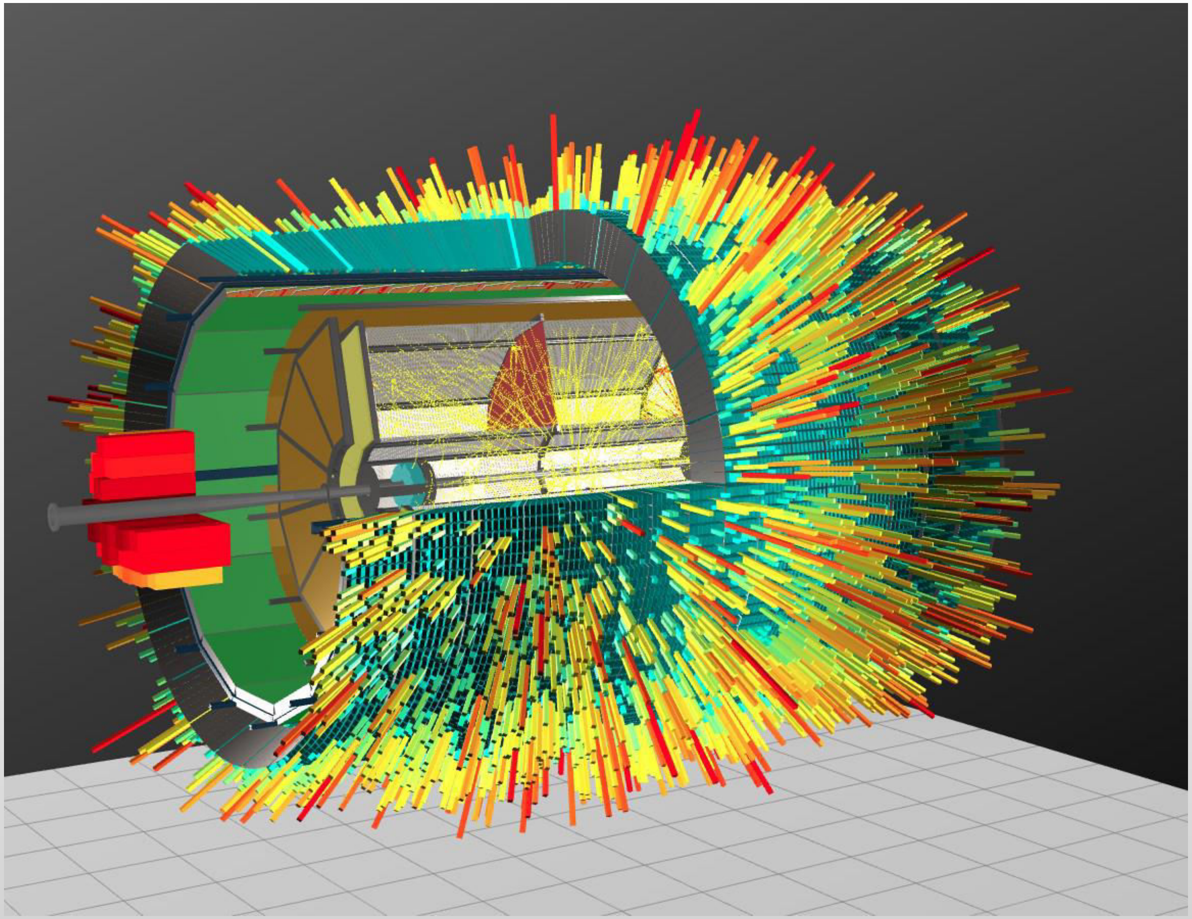
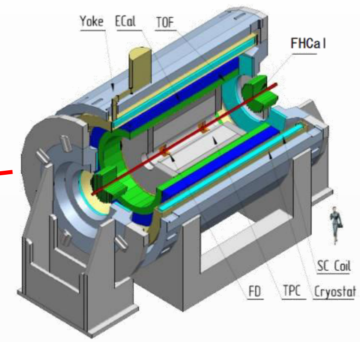
MPD Collaboration Status

V. Riabov for the MPD Collaboration



MPD at NICA

- One of two experiments at NICA collider to study heavy-ion collisions at $\sqrt{s_{NN}}$= 4−11 GeV

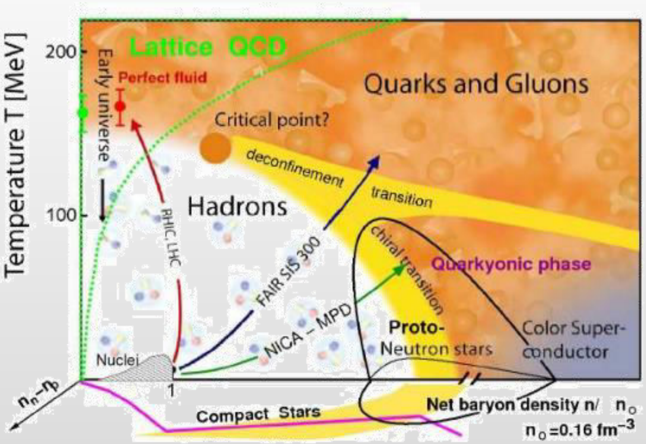


Stage- I

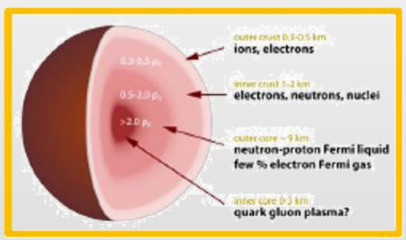
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$
TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

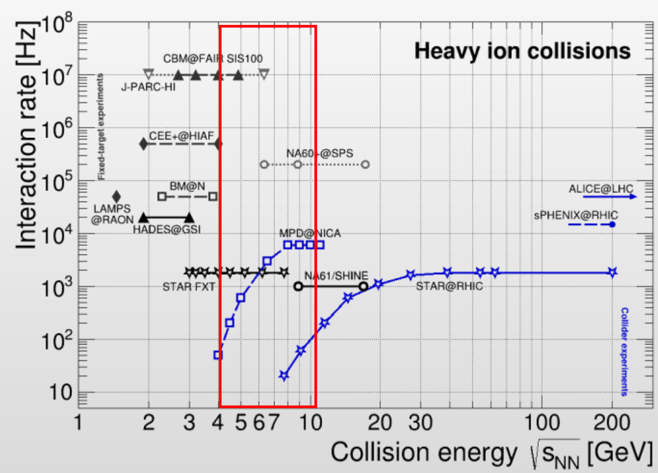
Expected configuration in first year(s) :

✓ not-optimal beam optics → wide z-vertex distribution, σ_z ~ 50 cm
✓ reduced luminosity (~10^{25}) → collision rate ~ 50 Hz
✓ first collision system → Xe+Xe / Bi+Bi @ 7 GeV max



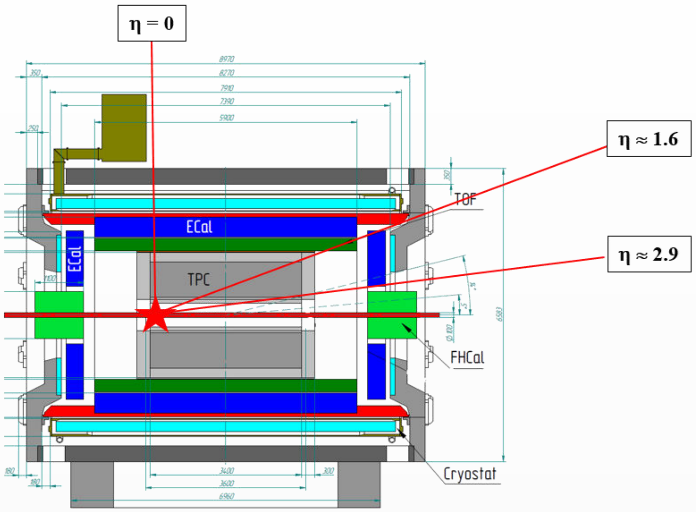
high baryon densities
→ inner structure of
compact stars

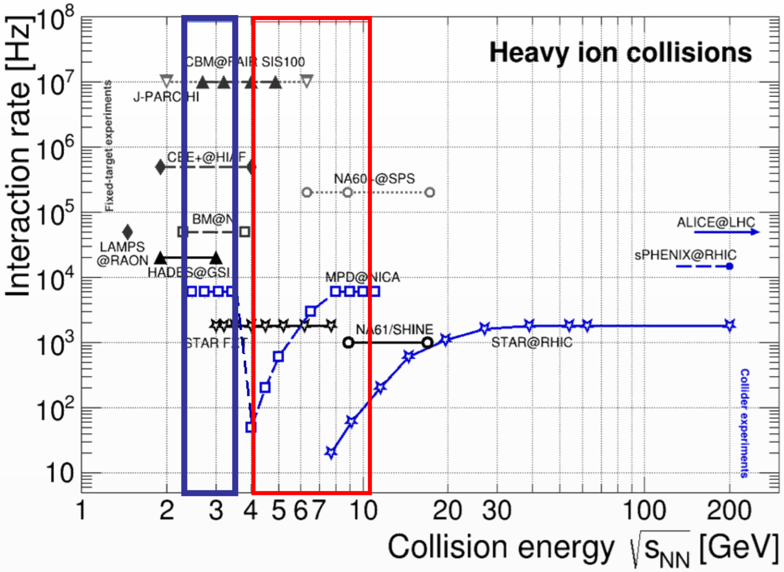




- NICA will study QCD medium at extreme net baryon densities → 1st order phase transition + QCD CEP
- Many ongoing (NA61/Shine, STAR-BES) and future experiments (CBM) in ~ same energy range

Fixed-target operation





- Option of MPD-FXT was approved by accelerator department (now default option)
- Fixed-target mode: one beam + thin wire (~ 100 µm) close to the edge of the MPD central barrel:
  - ✓ extends energy range of MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N and CBM)
  - ✓ solves problem of low event rate at lower collision energies (only ~ 50 Hz at $\sqrt{s_{NN}}$ = 4 GeV at design luminosity)
  - ✓ backup start-up solution (too low luminosity, only one beam, etc.)
- Collision systems: Xe (stable isotopes with A= 126, 128, 129, 130, 131, 132, 134) + W (A = 182, 183, 184, 186), Cu (A=63, 65), Au (A = 197), … subject of further discussions
- MPD detector is able to run in the fixed-target mode in the default configuration:
  - ✓ existing trigger system remains to be efficient (FFD + FHCAL + TOF)
  - ✓ detector provides reasonable p_T coverage for light/heavy identified hadrons at midrapidity (y_{CMS} ~ 0)

Capability of target and collision energy overlap between MPD and BM@N experiments

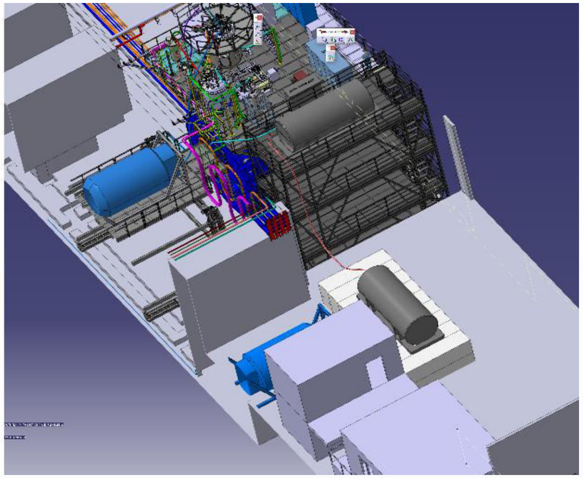
MPD schedule

❖ Latest estimates provided by V. Golovatyuk

	Year 2024	
17	**January 25th – March 10th**	**Cooling Solenoid to the temperature below of liquid Nitrogen 72K**
18	April – June 15th	Laying water cooling pipes and cable routing for Solenoid powering power supplies in the MPD Hall
19	**July 1 – 10th**	**Switching on Magnetic Field in the MPD Magnet** **A Cooling water supplying system of bld. 17 (MPD) must be ready to avoid further shifts of Time line**
20	July 15th - August 10th	Solenoid Safety regimes of emergent energy evacuation working out Development of algorithms of cooling on base of experience with manual regime
21	August19th. - November 19th	Magnetic Field measurements
22	Nov 20th - Nov 27th	Support Frame installation
23	November 20th – December 20th	Installation FHCal into poles
24	November 30th	TPC/Ecal Cooling system is commissioned
25	November 20th	TPC mechanical body is assembled, leak test and HV test are finished
26	November 30th	Production 40 ECal half sectors out of 50 are finished (light shifters problem)
	Year 2025	
27	December 2d – February 25th	Installation ECal sectors
28	January 13th – February 22d	Installation TOF modules (access from both sides)
29	March 3d – May 24th	TPC installation
30	January 13th – June 7th	Cabling
31	June 16th – June 27th	Mounting of the beam pipe

Activities in the MPD Hall

Temporary scheme of Solenoid cooling



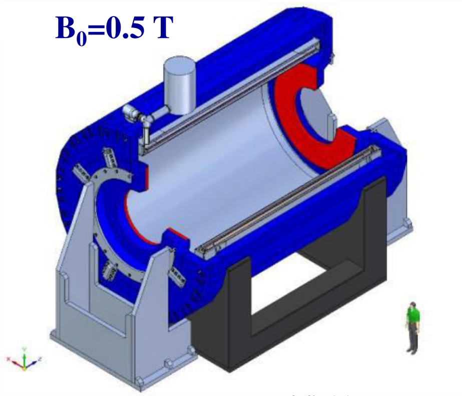
Cryogenic platform

Strings for cryogenic pipes and cables hold

- ❖ First cooling if the magnet to below LN2 temperature of ~ 70^0 K in February-March
- ❖ No problems with the cooling system or magnet reported
- ❖ Warming up to room temperature in April:
  - ✓ problems with LHe supply and tanks → now solved
  - ✓ problems with water cooling for power supplies and trim coils (evacuation of ~ 300 kW of heat)
- ❖ Colling straight to LHe temperature will be resumed once (will take 2-3 weeks):
  - ✓ water cooling is provided
  - ✓ quench protection system is setup and tested with equivalent load
- ❖ Colling of the magnet requires shifts for system monitoring and control → collaboration-wide issue

Barrel subsystems in production

SC Solenoid + Iron Yoke + Mapper

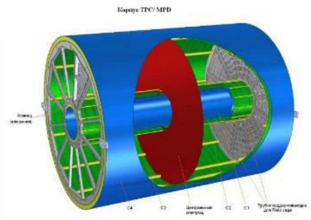


Novosibirsk BINP magnetic field mapper

Parameter	Value
Length of movement for Z	2× 4,5 m
Length of movement for R	0.1 – 2.2 m
Rotation of measurement block	3600
Accuracy of movement for Z	50 microns
Accuracy of movement for R	50 microns
Accuracy of rotation	0.20
Hall 3D sensor	HE444, HE Hoeben Electronix,
Hall 3D sensor accuracy	0.1 Gs
Hall 3D sensor accuracy total (with accuracy of laser tracker and temperature correction)	0.3 Gs
Sag of guide line	5 mm
Weight of mapper	100 kg
Reading time per one measurement	1 sec

Range of fields: 0.2-0.57 T (6 fields x 5 adjustments = 30 maps)
Total time of field measurements: ~ 4 months

TPC – central tracking detector



TPC cylinders, central membrane, service wheels, readout chambers, gas system - ready - final vessel assembly by the end of year

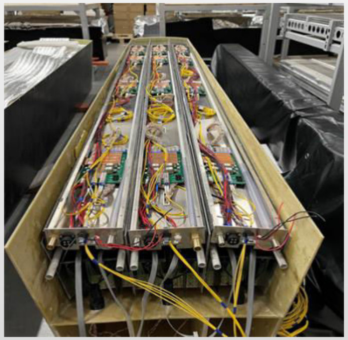
Support structure

Carbon fiber support frame delivered and unpacked, sagita ~ 5 mm at full load

TOF - ready

ECAL

Half-sectors at different stages of assembly



83% of calorimeter will be ready till November of 2024
The remaining 400 modules will be produced, delays with fiber supply
Production rate ~ 10 half-sectors per month
Installation procedure for electronics in half-sectors is under development

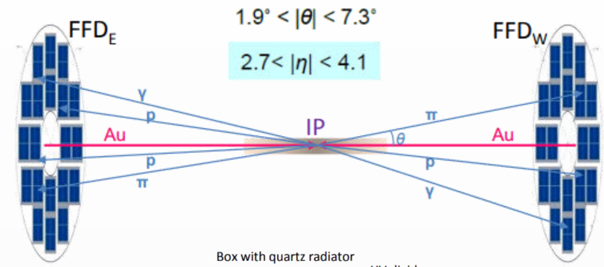
Forward subsystems in production

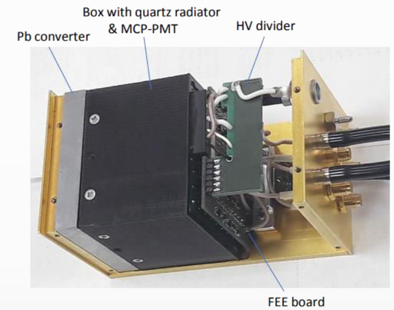
FHCAL

FHCal assembled on the platform is ready to be installed in the Pole.

FHCAL modules have been produced and tested → installation in autumn 2023

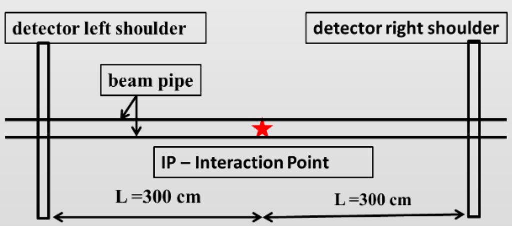
FFD





Cherenkov modules of FFDE and FFDW are available, mechanics of FFD sub-detectors is available for installation in container with vacuum beam tube

Beam and luminosity monitoring



Measurement of transverse sizes of the bunches
Transvers and longitudinal convergence of bunches
Vertices distribution along the beam

- Two sets by 32 scintillator counters readout by SIMPs from both sides
- Observables & methods:
  - ✓ counting rate and z-vertex distribution ($\sigma_{z\text{-vertex}}$ ~ 5 cm with $\delta\tau$ ~ 300 ps)
  - ✓ Van der Meer and ΔZ scans for optimization of beam optics
- Beam tests of prototypes
- Mass production of scintillator detectors

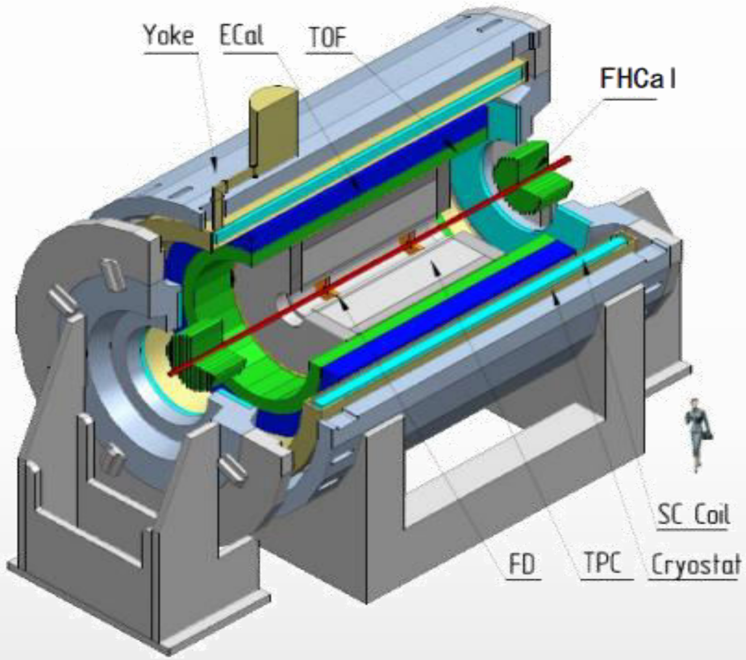
Multi-Purpose Detector (MPD) Collaboration

MPD** International Collaboration was established in **2018
to construct, commission and operate the detector

12** Countries, **>500** participants, **38** Institutes and **JINR

Organization

Acting Spokesperson:	***Victor Riabov***
Deputy Spokespersons:	***Zebo Tang, Arkadiy Taranenko***
Institutional Board Chair:	***Alejandro Ayala***
Project Manager:	***Slava Golovatyuk***



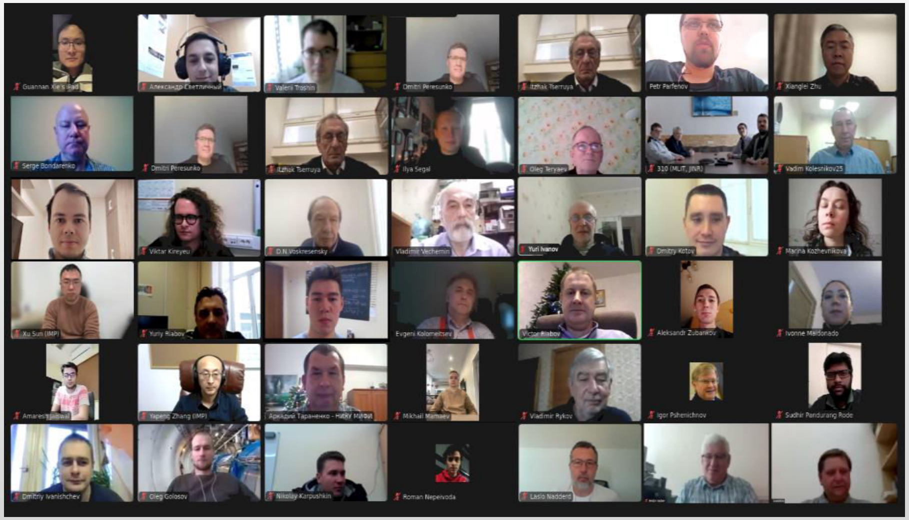
***Joint Institute for Nuclear Research, Dubna**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*SSI "Joint Institute for Energy and Nuclear Research – Sosny" of the National Academy of Sciences of Belarus, Minsk, **Belarus***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*University of Science and Technology of China, Hefei, **China**;*
*Huzhou University, Huzhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*University of Chinese Academy of Sciences, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics of CAS, Lanzhou, **China**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Institute of Physics and Technology, Almaty, **Kazakhstan**;*
*Benemérita Universidad Autónoma de Puebla, **Mexico**;*
*Centro de Investigación y de Estudios Avanzados, **Mexico**;*
*Instituto de Ciencias Nucleares, UNAM, **Mexico**;*
*Universidad Autónoma de Sinaloa, **Mexico**;*
*Universidad de Colima, **Mexico**;*
*Universidad de Sonora, **Mexico**;*
*Universidad Michoacana de San Nicolás de Hidalgo, **Mexico***
*Institute of Applied Physics, Chisinev, **Moldova**;*
*Institute of Physics and Technology, **Mongolia**;*

*Belgorod National Research University, **Russia**;*
*Institute for Nuclear Research of the RAS, Moscow, **Russia**;*
*High School of Economics University, Moscow, **Russia***
*National Research Nuclear University MEPhI , Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*National Research Center "Kurchatov Institute", **Russia**;*
*Peter the Great St. Petersburg Polytechnic University Saint Petersburg, **Russia**;*
*Plekhanov Russian University of Economics, Moscow, **Russia**;*
*St.Petersburg State University, **Russia**;*
*Skobeltsyn Institute of Nuclear Physics, Moscow, **Russia**;*
*Petersburg Nuclear Physics Institute, Gatchina**, Russia**;*
*Vinča Institute of Nuclear Sciences**, Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***

Conferences and workshops

- MPD presentations at conferences, last 6 months:
  - ✓ 2nd Workshop on Dynamics of QCD Matter, Bhubaneswar, 7-9 October, 2023
  - ✓ 73-rd International conference on nuclear physics "Nucleus-2023", Sarov, 9-13 October, 2023
  - ✓ India-JINR workshop on elementary particle and nuclear physics, and condensed matter research, Dubna, 16-19 October, 2023
  - ✓ XX Mexican School on Particles and Fields 2023, Mexico, 30 October - 3 November, 2023
  - ✓ Научная сессия Отделения физических наук РАН, г. Дубна, 1-5 апреля, 2024

- JINR-MEPhI organized International Workshop NICA-2023 (http://indico.oris.mephi.ru/event/301/overview):
  - ✓ 100+ participants from different countries:
    Belarus, Bulgaria, Israel, India, China, Kazakhstan, Mexica, Russia, Turkey, Serbia, USA and Uzbekistan
  - ✓ active participation of the MPD Chinese group in the organizing committee and the work of the workshop
  - ✓ 22 presentations in three days on experimental and theoretical topics
  - ✓ joint platform for discussion of NICA physics at BM@N and MPD



Co-chairs
Arkadiy Taranenko (MEPhI, JINR)
Evgeni Kolomeitsev (JINR, UMB, Banska Bystrica)
Victor Riabov (PNPI, MEPHI)

Organizing commitee
Zebo Tang (USTC, China)
Yi Wang (Tsinghua University, China)
Shusu Shi (CCNU, China)
Natalia Barbashina (MEPhI)
Ivan Astapov (MEPhI)
Dmitry Blau (NRC Kurchatov Institute)
Serge Bondarenko (BLTP JINR)
Fedor Guber (INR RAS)
Vadim Kolesnikov (JINR)

MPD physics program

G. Feofilov, A. Aparin

Global observables
- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations
- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

D. Peresunko, Chi Yang

Electromagnetic probes
- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

Heavy flavor
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

❖ Alexey Aparin steps down as PWG-1 convener – thanks for service !!!

❖ Petr Parfenov steps in as a new PWG-1 convener – welcome !!!

❖ Cross-PWG format of meetings for discussion of results and analysis techniques

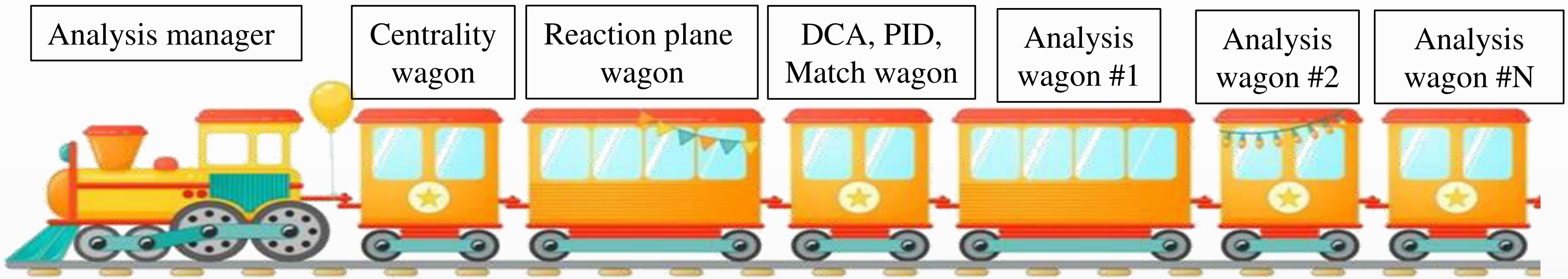
Big data productions

- Physics feasibility studies using centralized large-scale MC productions → consistent picture of the MPD physics capabilities with the first data sets, preparation for real data analyses
- https://mpdforum.jinr.ru/c/mcprod/26:
  - Request 25: General-purpose, 50M UrQMD BiBi@9.2 → **DONE**
  - Request 26: General-purpose (trigger), 1M DCM-QGSM-SMM BiBi@9.2 → **DONE**
  - Request 27: General-purpose (trigger), 1M PHQMD BiBi@9.2 → **DONE**
  - Request 28: General-purpose with reduced magnetic field, 10M UrQMD BiBi@9.2 → **DONE**
  - Request 29: General-purpose (hypernuclei), 20M PHQMD BiBi@9.2 → **DONE**
  - Request 30: General-purpose (polarization), 15M PHSD BiBi@9.2 → **DONE**
  - Request 31: General-purpose (femtoscopy), 50 M UrQMD BiBi@9.2 with freeze-out → **DONE**
  - Request 32: General purpose (flow), 15M vHLLE+UrQMD with XPT → **DONE**
  - Request 33: General purpose (FXT), (11M x 3 energies) UrQMD (mean field) → **DONE**
- Production comparable in size to the first expected real data samples test the existing computing and software infrastructure
- Develop realistic analysis methods and techniques, set priorities and find group leaders
- Thanks to A. Moshkin (production manager), LIT specialists, computing/software team !!!

Handling the big data sets

- ❖ Centralized Analysis Framework for access and analysis of data → Analysis Train:
  - ✓ consistent approaches and results across collaboration, easier storage and sharing of codes and methods
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes

- ❖ Analysis manager reads event into memory and calls wagons one-by-one to modify and/or analyze data:



- ❖ The Analysis manager and the first Wagons have been created, in MpdRoot @ mpdroot/physics
- ❖ First Analysis Train runs started in September, 2023 → regular runs on request ever since
- ❖ Train takes ~ 12 hours to process 50M events for 10-15 wagons (1 year of CPU time)
- ❖ Many new services and improvements (improved PID parameterizations, new wagons):
  - ✓ https://indico.jinr.ru/event/4401/: constrained tracks, track ID refits
  - ✓ https://indico.jinr.ru/event/4314/: track quality selections
- ❖ Train becomes a new standard for physics (feasibility) studies
- ❖ Eventually all analysis codes should be committed to MpdRoot as Wagons

Second collaboration paper

- PWG1:
  - Trigger efficiency and biases
  - T0 resolution and multiplicity-dependent corrections
  - Centrality, EP event categorization
- PWG2:
  - Resonances (rho(770), phi(1020), K0(892), Sigma(1385)+/-, Lambda (1520)), pT-differential yields
  - Charged hadrons (\pi, K, p, pbar)
  - Hyperons (\Lambda, \Ksi, \Omega)
  - (anti)Lambda polarization
  - Light (hyper) nuclei
- PWG3:
  - 1D pion femtoscopy (2 kT bins and 2-3 centrality bins); factorial moments; charged balance function
  - Factorial moments for different type of EoS (crossover phase transition XPT, first order phase transition XPT)
  - Chaoticity parameter in two-pion correlation functions
  - Anisotropic flow (v1, v2, v3) vs. pT, rapidity, centrality for charged pions, kaons, protons + using two-particle (EP,SP) and 4-particle cumulants
- PWG4:
  - Neutral meson (pi0, eta) pT/centrality-differential yields and flow
  - Neutral meson (pi0, eta) pT/centrality-differential yields and flow
  - Dileptons
- PWG5:
  - ???

Plan is to prepare a paper draft by the next Collaboration meeting
→ only analyses in the advanced state can be included

What's next?

- Two obvious options:
  - ✓ Xe – most probable first beam specie
  - ✓ T = 2.5 GeV – maximum kinetic energy of the beam, limitation of the fast extraction system
  - ✓ Nuclotron-to-Collider transport line assembled from available magnets → may result in additional limitations
  - ✓ Luminosity – optimistically 10^{25} $cm^{-2}s^{-1}$

- Xe+Xe @ ~ 7 GeV, collider mode:
  - ✓ not much difference for analysis techniques and expectations wrt. to BiBi @ 9.2 GeV
  - ✓ collected statistics might be small due to low luminosity and short beam lifetime

- Xe+W @ ~ 2.8 GeV, fixed-target mode:
  - ✓ "terra incognita" for detector performance and physics capabilities
  - ✓ may provide most of statistics for physics analyses in the first years

Have to weigh the pros and cons and make a major decision for further physical analyses

New MPD Collaboration web site

mpd.jinr.ru

General information ˅ Collaboration ˅ MPD Setup ˅ Presentations ˅ Publications ˅ Meetings ˅

GENERAL INFORMATION
- MPD DOCUMENTS
- NEWS AND ANNOUNCEMENTS
- UPCOMING EVENTS
- MPD FORUM
- CONTACTS
- MAILING LISTS

COLLABORATION
- PARTICIPANTS INSTITUTIONS
- EXECUTIVE COUNCIL
- INSTITUTIONAL BOARD
- TECHNICAL BOARD
- PHYSICS COUNCIL
- SPEAKER'S BUREAU
- COLLABORATION LIST

MPD SETUP
- DETECTOR
- SOFTWARE

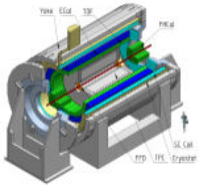
MPD PRESENTATIONS
- SEMINARS
- TALKS AT CONFERENCES

MPD PUBLICATIONS
- COLLABORATION PUBLICATIONS
- PUBLISHED PAPERS
- DISSERTATIONS AND DIPLOMAS

MPD MEETINGS
- CROSS-PWG MEETINGS
- COLLABORATION MEETINGS
- MINUTES

The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nuclotron-based Ion Collider fAcility (NICA), one of the flagship projects at the Joint Institute for Nuclear Research (JINR). Its main scientific purpose is to search for novel phenomena in the baryon-rich region of the QCD phase diagram by means of colliding heavy nuclei in the energy range of 4 GeV$<\sqrt{s_{NN}}<$11GeV. A wealth of results, obtained by colliding heavy ions at different beam energies, has been gathered by experiments at SIS, AGS, SPS, RHIC and the LHC facilities. The new experimental program at the NICA-MPD will fill a niche in the energy scale, which is not yet fully explored, and the results will bring about a deeper insight into hadron dynamics and multiparticle production in the high baryon density domain.

It is foreseen that the MPD will be installed in two stages. The first stage of the detector configuration is planned to be ready for commissioning in 2025. The overall set-up of the MPD and the spatial arrangement of detector subsystems in the first stage are shown in the figure.



The "central barrel" components have an approximate cylindrical symmetry within $|\eta|<1.5$. The beam line is surrounded by the large volume Time Projection Chamber (TPC) which is enclosed by the TOF barrel. The TPC is the main tracker, and in conjunction with the TOF they will provide precise momentum measurements and particle identification. The Electromagnetic Calorimeter (ECal) is placed in between the TOF and the MPD magnet. It will be used for detection of electromagnetic showers, and will play the central role in photon and electron measurements. The MPD superconducting solenoid magnet is designed to provide a highly homogeneous magnetic field of up to 0.57 T (with a default operational setting of 0.5 T), uniform along the beam direction, to ensure appropriate transverse momentum resolution for reconstructed particles within the range of momenta of 0.1-3 GeV/c. As the average transverse momentum of the particles produced in a collision at NICA energies is below 500 MeV/c, the detector was designed to have a very low material budget. In the forward direction, the Fast Forward Detector (FFD) is located still within the TPC barrel. It will play the role of a wake-up trigger. The Forward Hadronic Calorimeter (FHCal) is located near the magnet end-caps. It will serve for determination of the collision centrality and the orientation of the reaction plane for collective flow studies.

Additional detectors are proposed in the later stages. The silicon-based Inner Tracking System (ITS) will be installed

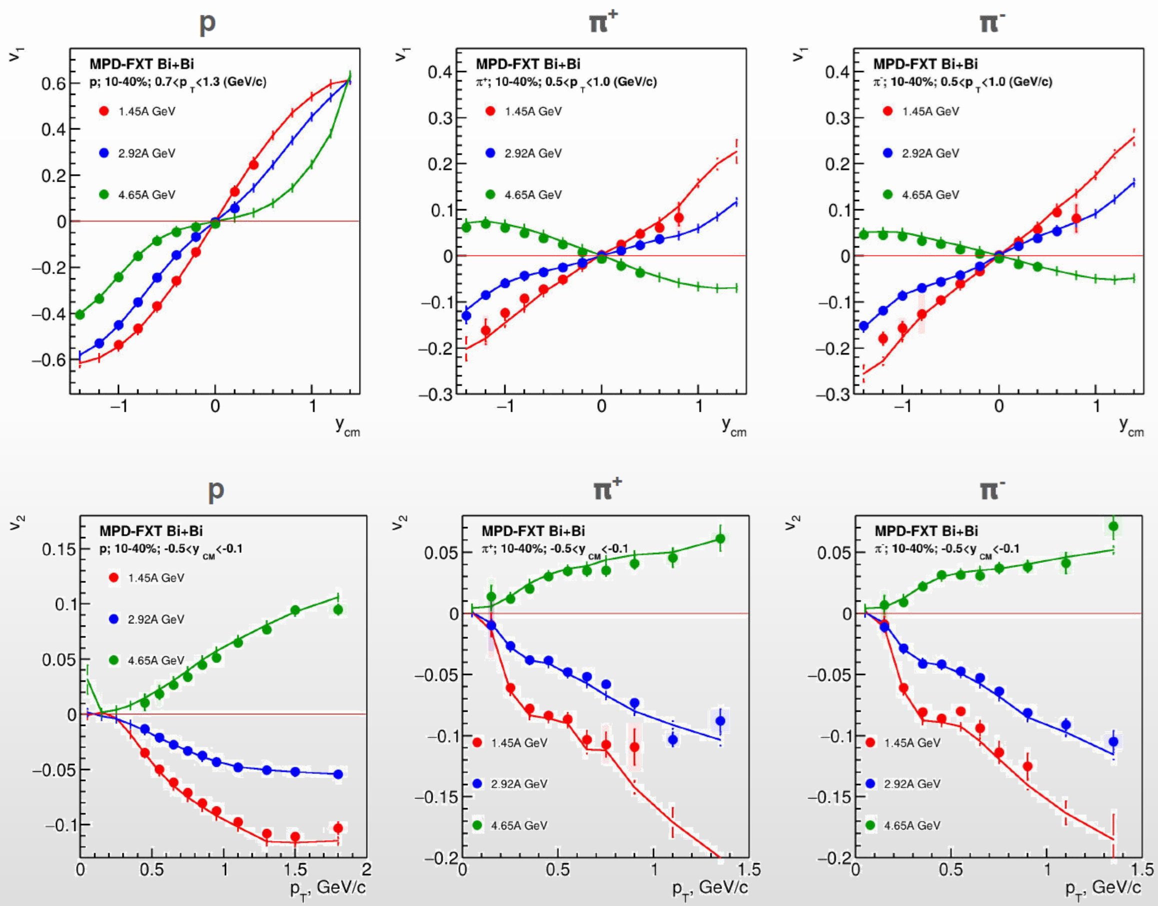
Advancements in analyses

MPD-FXT, v_1 & v_2 for protons/pions

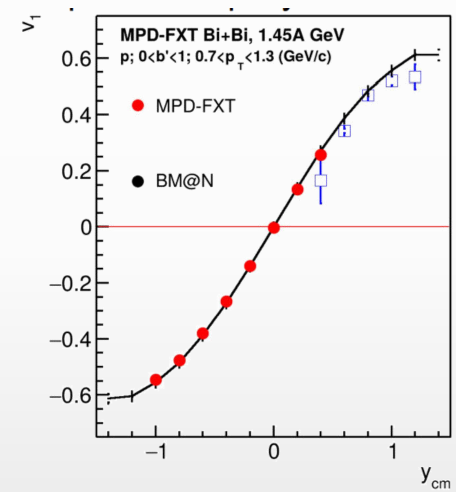
- Request 33 mass production (UrQMD mean-field, fixed-target mode), BiBi @ 2.5, 3.0 and 3.5 GeV
- New: realistic PID (TPC+TOF); efficiency corrections; centrality by TPC multiplicity

v_1 vs. rapidity

v_2 vs. p_T



MPD vs. BM@N



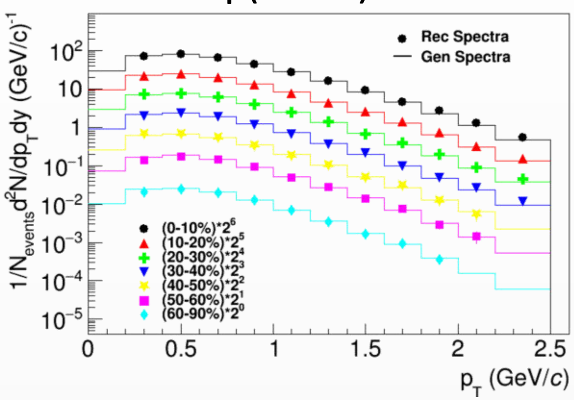
Reconstructed v_1 & v_2 are quantitatively consistent with truly generated signals

MPD and BM@N complete each other with modest overlap

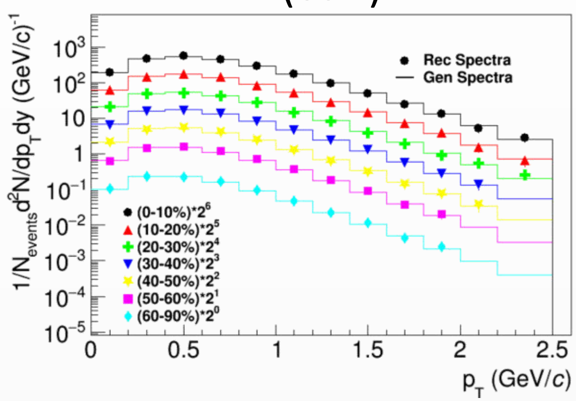
Resonances

- Request 25 mass production (UrQMD), BiBi @ 9.2 GeV
- New: Analysis Train request #6, most realistic approach to data analysis; centrality dependence

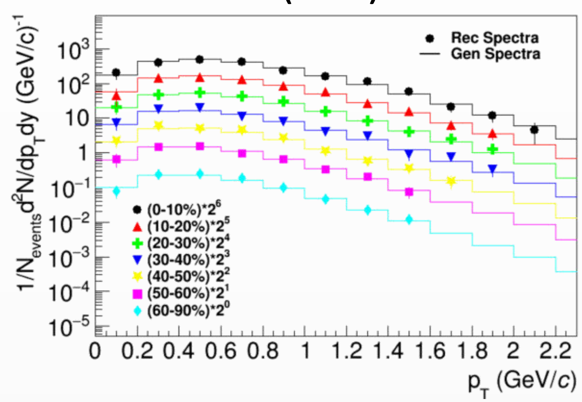
ϕ(1020)



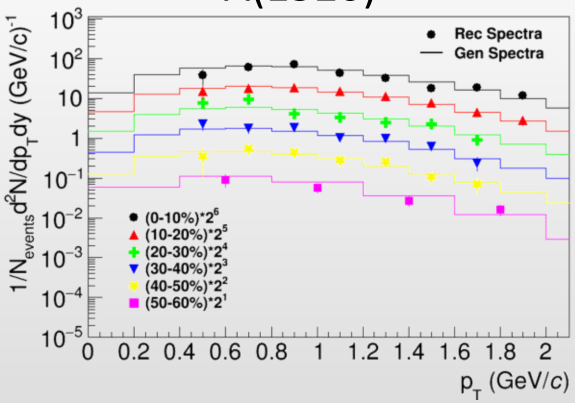
K*(892)⁰



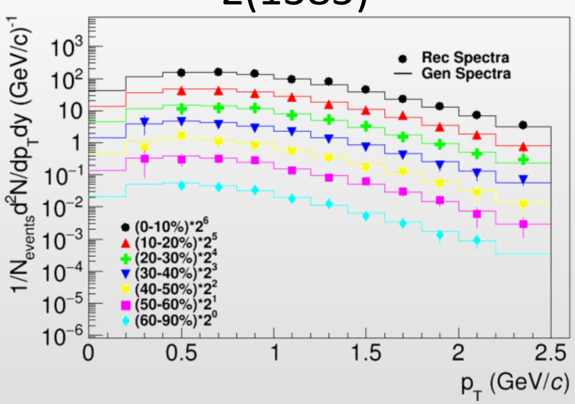
K*(892)±

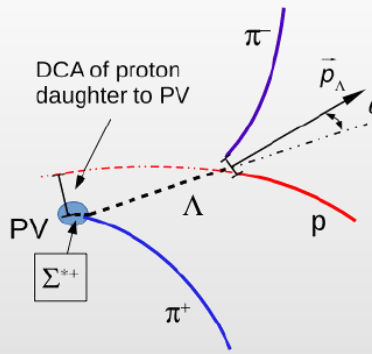


Λ(1520)



Σ(1385)±





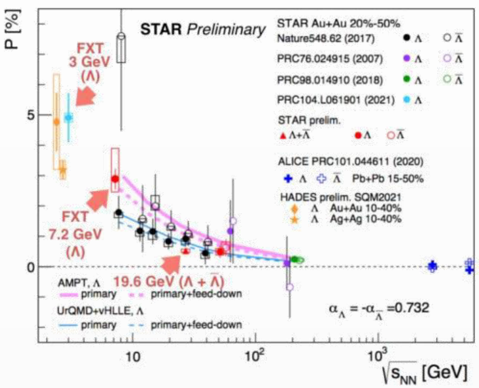
Reconstructed spectra match the truly generated ones within uncertainties

Centrality dependent analysis would require ≥ 50 M A+A events

Measurements are possible starting from ~ zero momentum → sample most of the yields

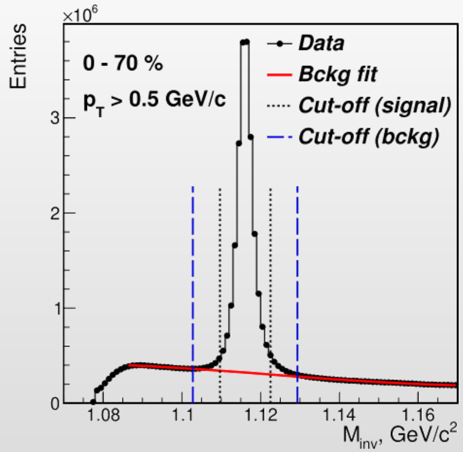
Hyperon global polarization

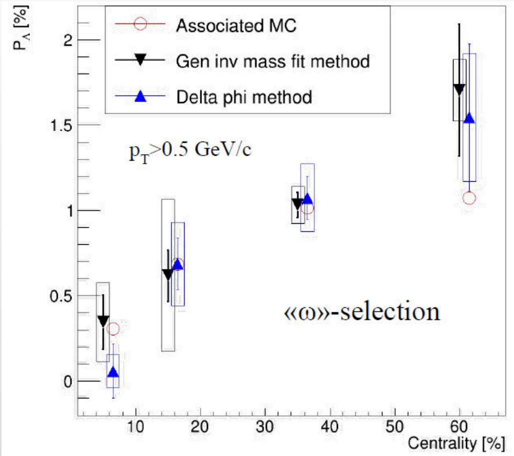
- BiBi@9.2 GeV (PHSD), 15 M events → full event/detector simulation and reconstruction
- Global hyperon polarization (thermodynamical Becattini approach) by PHSD event generator

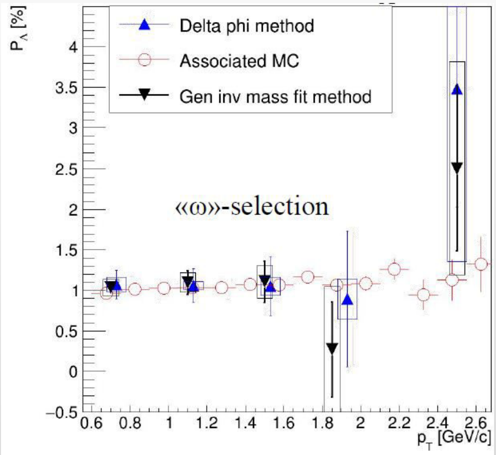


- Two analysis methods:
  - ✓ Δφ-method
  - ✓ Generalized invariant mass fit method - default
- Full reanalysis
- "Performance study of the hyperon global polarization measurements with MPD at NICA" → recently accepted to EPJA

- Reconstruction of Λ global polarization, BiBi@9.2 GeV:





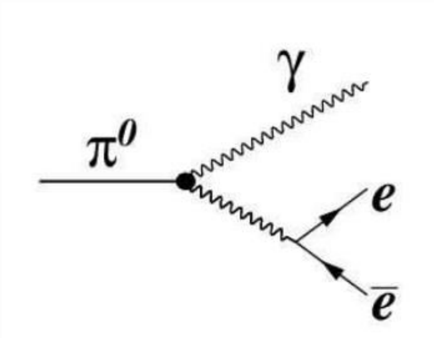


Both methods have an agreement with associated MC

The statistics size of 15M events is not enough for p_T-η measurements

Neutral mesons (π^0)

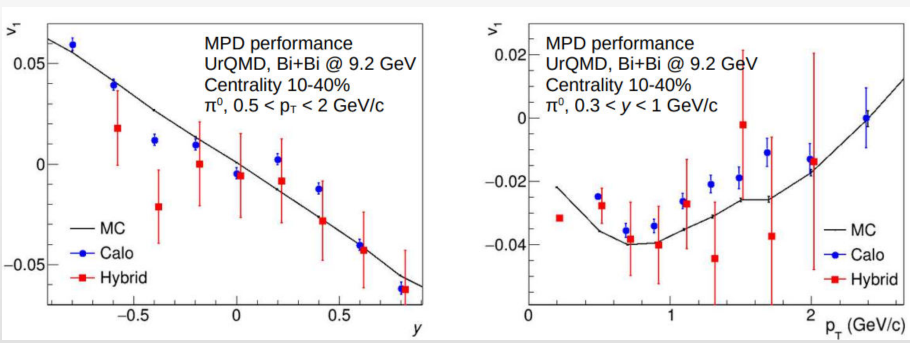
- Request 25 mass production (UrQMD), BiBi @ 9.2 GeV
- New: Analysis Train request #5, most realistic approach to data analysis



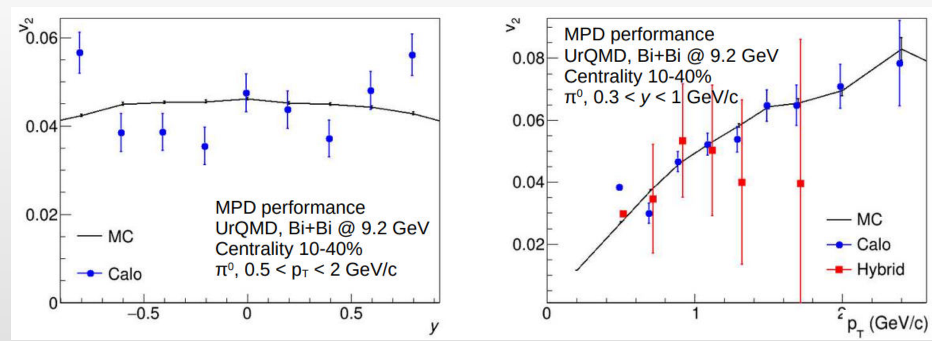
- Two photon reconstruction techniques:
  - ✓ ECAL
  - ✓ photon conversion
- Three techniques for meson reconstruction:
  - ✓ ECAL-ECAL
  - ✓ ECAL-conversion
  - ✓ Conversion-conversion

- v_1 and v_2:

v_1 vs. rapidity and p_T



v_2 vs. rapidity and p_T



Reconstructed v_1 and v_2 qualitatively consistent with generated signals

Hybrid method generally requires higher statistics

Small value of generated v_2 requires higher statistics for all methods

Summary

- ❖ Preparation of the MPD detector and experimental program is continued
- ❖ Consider different operation options (collider, fixed-target)
- ❖ Develop realistic analysis methods and techniques to be ready for analysis of the first data

BACKUP